Evaluation for optimal stress system for cardiac MR study

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Introduction Changes in regional myocardial perfusion function can be assessed by paramagnetic contrast or radionuclide imaging in conjunction with exercise stress. Frequently, exercise stress can be implemented within the MRI magnet bore by handgrip stress testing. Such an approach has been used to induce changes in myocardial metabolism or regional wall motion during magnetic resonance imaging or spectroscopy. Generating a stable, moderate level of stress in a high field magnet during MR acquisition is technically difficult. During the stress session, the patient is verbally coached to squeeze the handgrip stressor to employ about 30% of the maximal voluntary contraction (MVC) for 5 to 10 minutes: being asked to increase or decrease the grip pressure whenever the stress level changes from the predetermined level. It is particularly important to maintain a continuous and constant handgrip stress level during cardiac ^{31}P MR spectroscopy. Otherwise, metabolic changes tend to recover quickly, and any change would disappear with involuntary reduction of the stress. In practice, it is difficult for patients in the magnet to maintain a constant level of stress with verbal coaching due to temporal and biological lag. Moreover, involuntary adaptation of the patients stress level would interfere with the measurement of such changes. We have developed a PC-based handgrip stress control system [1] that is executed remotely by audio-visual signals to the patient. In this study, we have refined the control system and evaluated the performance of the stress control system for use within a high field clinical MR scanner environment.

Methods The system flow diagram is shown in Figure 1. A handgrip stressor is made of a compression-load-cell strain gauge and controller. The load-cell/strain-gauge provides the signal source of the system. The system samples the handgrip pressure 10 to 20 times per second. The output is connected to a preamplifier and is calibrated in units of either [psi] or [kPa]. The digital signal from the handgrip stressor is sent to the PC serial port through an RS-232 data interface board. The signal is received using PC's HyperTerminal and Matlab® serial port platform. Predetermined control band, typically ±12.5%, near 30% MVC was set such that an error signal would be induced when the stress level is outside of the preset band. By the feed-forward or feedback control, the error-signals actuate audio-visual stimulation to coach the subject in the magnet using a LCD screen and headphone. Cardiac stress ^{31}P MR spectroscopy was performed in eight episodes from the six healthy volunteers in a 3T MR platform (General Electric HDxt). Each subject has two sets of stress cardiac MRS acquisitions: one with the new control system and the other with conventional verbal communication. Three spectra were collected for each set of the MRS study: at rest, during stress and with recovery. During the stress, 30% of MVC was employed using the handgrip strain gauge. The performance of the handgrip stress control system was evaluated using the average change in high energy phosphate and inter-subject variation.

Results and Discussion The automatic control system successfully provided feedback to human subjects to maintain a continuous and constant stress level during the stress session. Characteristic time course of the stress from the same subject is illustrated in Figure 2. In this typical case, the stress level was demonstrated to be substantially more stable with the automatic control system than with verbal communication: the higher the stress level, the more the deviation from the desired stress (Figure 3). For healthy volunteers, the range of the change in PCr/ATP during handgrip stress was not significantly different between these two types of stress sessions: 2.6% for stress with the new control system and 3.4 % for stress with verbal communication (p>0.7). The inter-subject variation with the control system, however, was far less than that with verbal communication: 5.5% and 9.2%, respectively (Figure 4).

It was demonstrated that the automated stress control system has made the stress level more constant and inter-subject variation reduced in the MR scanner. In light of this improvement, one can obtain more accurate measurements of the changes in metabolites, and higher spectral resolution by stabilizing movement with proactively using a sustained stress level during ^{31}P MRS.

Reference [1] Kim HW, et al. ISMRM 1784 (2009).

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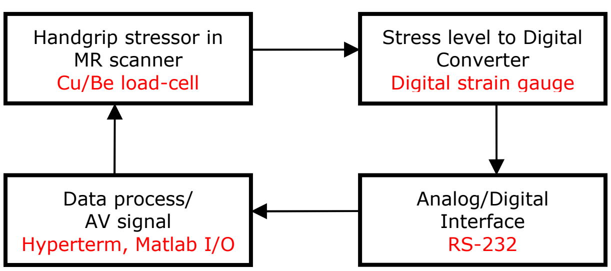

Figure 1. System flow diagram

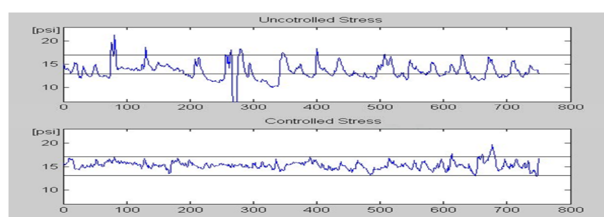

Figure 2. Typical stress time course: with verbal coaching (above), with automatic control (below).

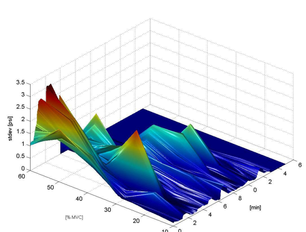

Figure 3. Standard deviation of the sampling grip pressure without the control system. The deviation is more significant as the handgrip pressure increases.

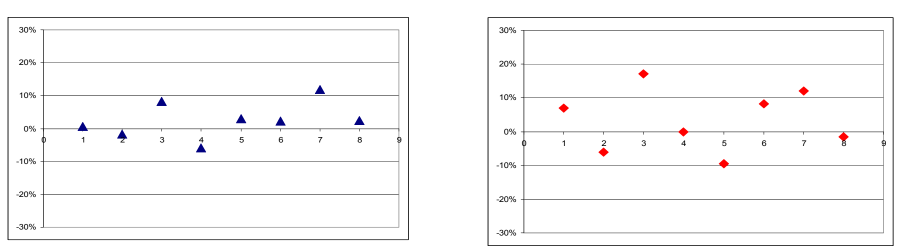

Figure 4. Percent change in myocardial PCr/ATP during handgrip stress. Each of eight studies with healthy volunteers had two different stress ^{31}P cardiac MRS: 1) with the automatic stress control system (left), and 2) with verbal communication (right). The changes between the two have a similar range but studies with verbal communication have larger inter-subject deviation.